

Design of Ultra Wideband Antennas in the Form of Planar Electric or Magnetic Monopoles

A. M. Abbosh⁽¹⁾, M.E. Bialkowski⁽¹⁾,

⁽¹⁾School of ITEE, University of Queensland, Qld. 4072, Australia
abbosh@itee.uq.edu.au

Abstract

An efficient approach to design ultra wideband (UWB) antennas in the form of planar electric and magnetic monopoles is presented. Simple design formulas for this type of radiators are described and their validity is tested via full electromagnetic analysis with Ansoft High Frequency Structure Simulator (HFSS). In the presented examples, Low Temperature Cofired Ceramic (LTCC) in the form of 1mm thick DuPont951 material is assumed as the antenna substrate. The presented results show that using this substrate, very compact UWB antennas can be developed. Simulations using HFSS prove the high accuracy of the proposed design method. The designed antennas feature near omnidirectional characteristics and good radiation efficiency.

1. Introduction

Recent years have witnessed an increased interest in ultra wideband (UWB) antennas since the adoption of UWB technology by US-FCC in 2002 which assigned the frequency band of 3.1-10.6GHz for UWB applications [1]. It is envisaged that UWB can bring significant advances particularly in wireless communications as a remedy to the existing frequency spectrum congestion. In addition to solving the spectrum congestion problem, UWB has potential to deliver high data rate transmission. In parallel to developing UWB technology recent research has been focused on reducing the size of front end modules in wireless transceivers by using multi-layer low temperature co-fired ceramic (LTCC) structures [2]. Many wireless systems have already discovered the benefits of LTCC technology. This is because it can not only deliver extremely small package size but also offers good electrical performance, high reliability, excellent thermal stability, superb unit to unit repeatability, and low cost.

The usual requirement for a wireless equipment is that the front end has to be connected to a radiating element, antenna. This creates a challenge to the designer when the front end is developed in LTCC. The reason is that it is not easy to connect or electromagnetically couple a separate antenna to the LTCC circuit. The method proposed and investigated in this paper is to use the upper layers of the LTCC to build the antenna.

In order to achieve an UWB performance a number of antenna candidates can be investigated. First, the designs utilizing a radiating element being perpendicular to the ground plane [3] have to be discarded. The reason is that they are unsuitable for integration with LTCC. As a result, only planar UWB antennas need to be considered. Those include a planar volcano-smoke slot antenna [4], a coplanar waveguide fed bowtie/triangular patch antenna [5], a multi-structure coplanar waveguide (CPW) fed [6], a multi-resonance planar patch antenna [7] and a printed monopole [8]. Elliptical and circular radiating elements to form planar UWB antennas have been reported in [9-10].

The main shortcoming of the designs of these planar UWB antennas is that they are based on the trial and error method. In order to obtain an optimal design, computationally intensive full wave electromagnetic simulations are usually applied. However, when one decides to obtain an antenna with a similar performance using a different dielectric substrate, the time consuming design process has to be fully repeated. This is not welcome by designers, which do not have access to sophisticated EM analysis and design software packages.

This paper addresses this shortcoming by providing simple design formulas which are suitable for UWB antennas in the form of planar monopoles fed from a microstrip line. The difference between values of the design parameters, i.e. dimensions of antenna structure, is less than 10% compared to the optimum values that are obtained using the commercial software Ansoft HFSS. Section 2 of this paper describes the proposed design method and section 3 presents results of simulation using Ansoft HFSS while section 4 concludes the paper.

2. Design

Configurations of the UWB antennas, which are investigated here, are presented in Fig.1. The structures shown in Fig.1a and 1b are identified as planar electric monopoles. These are created by a planar conducting surface formed by the intersection of either two ellipses or two circles in a two-side conductor-coated substrate. In these structures, the surface electric current flowing on an elliptical or circular shaped conductor is regarded as the primary source of radiation. In turn, the structures shown in Fig.1c and 1d are complementary to those in Fig. 1a and 1b and are named here as planar magnetic monopoles. In these structures, the electric field (or its surface magnetic current equivalent) in an elliptical or circular shaped slot is regarded as the primary source of radiated field.

The use of the terms of electric and magnetic monopole, which are introduced here, requires an extra explanation. The reason is that these primary radiators are accompanied by the presence of a tapered slot, which is created between the upper conductor and the ground plane. This slot plays a considerable role in obtaining wideband performance. It can be regarded as some form of a tapered slot antenna whose broadband operation is governed by the size of its opening. This opening has to be about half-wavelength at the lowest frequency of operation. As a result of this explanation it becomes apparent that both the shape of electric / magnetic monopole and of the tapered slot is responsible for broadband operation of the introduced antennas.

Here, we present simple design formulas to achieve broadband operation of the radiating structures of Fig. 1a-d. We commence this process with the assumption that a microstrip line feeding these structures is chosen to be with dimensions realizing $50\text{-}\Omega$ characteristic impedance. In addition, we assume that the size of the gap (g) between the monopole and the ground plane is similar to the microstrip line width. Input impedance is only slightly sensitive to this parameter and here g is chosen in the order of 1mm. The remaining design steps are summarized as follows.

1) Depending on the lowest frequency of operation (f_1), thickness of the substrate (h) and its dielectric constant (ϵ_r), width (w) and length (l) of the antenna structure including the feeder can be calculated [11];

$$w = \frac{c}{2f_1 \sqrt{\epsilon_r + 1}} \quad (1)$$

$$l = \frac{c}{2f_1 \sqrt{\epsilon_{re}}} - 2\Delta l \quad (2)$$

$$\epsilon_{re} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + 12 \frac{h}{w} \right]^{-0.5} \quad (3)$$

$$\Delta l = 0.412h \frac{(\epsilon_{re} + 0.3)(0.264 + w/h)}{(\epsilon_{re} - 0.258)(0.8 + w/h)} \quad (4)$$

where c is speed of light in free space and ϵ_{re} is the effective dielectric constant. We will assume that w is extended along the x -axis while l is extended along the y -axis. As we are in the preliminary stage of the design then the parameter Δl is neglected as it has usually a small value assuming that $w/h \gg 1$.

2) The radiating slot is formed by the intersection of two ellipses (or circles) in the manner shown in Fig.1. The secondary diameter of the ellipses, or the diameter of the circles (D_1 & D_2) and ratio of the secondary diameter to the major diameter in the two ellipses (R_1 & R_2) in the preliminary stage of the design are equal to;

$$D_1 = w \quad (5)$$

$$D_2 = w/2 \quad (6)$$

$$R_1 = R_2 = 0.5 \quad (7)$$

Equations (5) and (6) indicate that the preliminary values of D_1 and D_2 are chosen to be comparable to half and quarter of the effective wavelength, at the lowest frequency of operation, respectively.

3) Centres of the two ellipses or the two circles are shifted by a certain distance from centre of the ground plane in order to get the best match to the 50Ω feeder. Parts of the two ellipses that extend outside the ground plane from one direction are cut.

4) The ground plane in all cases is in the shape of a half ellipse whose diameter D_3 and ratio of its secondary to primary radius R_3 are chosen as;

$$D_3 = \frac{C}{2f_1 \sqrt{\epsilon_{re}}} \quad (8)$$

$$R_3 = 0.5 \quad (9)$$

5) Width of the microstrip transmission line, w_m to give characteristic impedance Z_o equal to 50Ω can be calculated using the following equations [12];

$$Z_o = \frac{60}{\sqrt{\epsilon_{me}}} \ln\left(\frac{8h}{w_m} + \frac{w_m}{4h}\right) \quad (10a)$$

for $w_m / h \leq 1$, and

$$Z_o = \frac{120\tau}{\sqrt{\epsilon_{me}}[w_m / h + 1.39 + 0.67 \ln(w_m / h + 1.44)]} \quad (10b)$$

for $w_m / h \geq 1$, where ϵ_{me} is the effective dielectric constant for the transmission line and it is given by;

$$\epsilon_{me} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2 * \sqrt{1 + 12h / w_m}} \quad (11)$$

In order to demonstrate the validity of the above presented formulas, we present a number of designs assuming an LTCC substrate in the form of DuPont951 material with $\epsilon_r=7.8$, tangent loss=0.0015 and thickness=1mm. Parameters for UWB slot antennas obtained with the above presented formulas method, as well as the optimized values are shown in Table 1 assuming a 2.5GHz value for (f_1). The optimization was performed for the best impedance bandwidth with near omnidirectional characteristics. The presented values show that the designed UWB antennas can be of very compact size, which is advantageous in applications requiring very compact RF front ends.

3. Results

The simulations of the four configurations of UWB antennas were performed with Ansoft HFSSv9.2 on a PC with dual Xeon 2.8GHz processors and 3.5GB of RAM as a simulation platform. Radiation boxes used with HFSS to plot the radiation pattern and measure gain had dimensions in the x , y and z directions more than a quarter wavelength (at the lowest frequency of operation) away from the antenna structure [13].

Figure 2 shows variation of the return loss with frequency for the four designed antennas. The obtained results indicate that the designed antennas have UWB characteristics with an impedance bandwidth which covers the UWB frequency band assuming a 10dB return loss reference. From the UWB applications point of view the antenna is usually required to have an omnidirectional radiation. This requirement is fulfilled over the whole bandwidth as shown in Fig.3 for the elliptical electric monopole. Similar results were obtained for the other designed antennas.

Gain of the designed antennas is revealed in Fig.4. It varies between about 0.5dB to 4.7dB over the required bandwidth for the electric monopoles while it is between - 0.5dB to 2.5dB for the magnetic monopoles. These results

indicate that the electric monopoles show a higher gain compared to their magnetic counter parts.

Using a substrate with a high dielectric constant and a direct microstrip feeder may cause deterioration in the radiation efficiency of the antenna. To check this case, variation of the surface efficiency with frequency for the designed antennas was calculated with HFSS software. These calculations have shown that the designed antennas have always a good efficiency which is greater than 92%.

4. Conclusions

In this paper, a simple method for designing planar UWB antennas in the form of planar electric or magnetic monopoles has been presented. In the chosen configurations, the radiating structure is formed by the intersection of two ellipses or two circles. For an electric dipole, an electric current flowing on the conductor forming the monopole is responsible for radiation. In turn, in a magnetic dipole, an electric field in a slot performs a complimentary function. Computer simulations have shown that the proposed design formulas provide UWB antenna dimensions which differ by less than 10% from the optimized ones. The designed antennas cover the band allocated to UWB systems with well behaved omnidirectional radiation pattern and more than 92% radiation efficiency.

5. References

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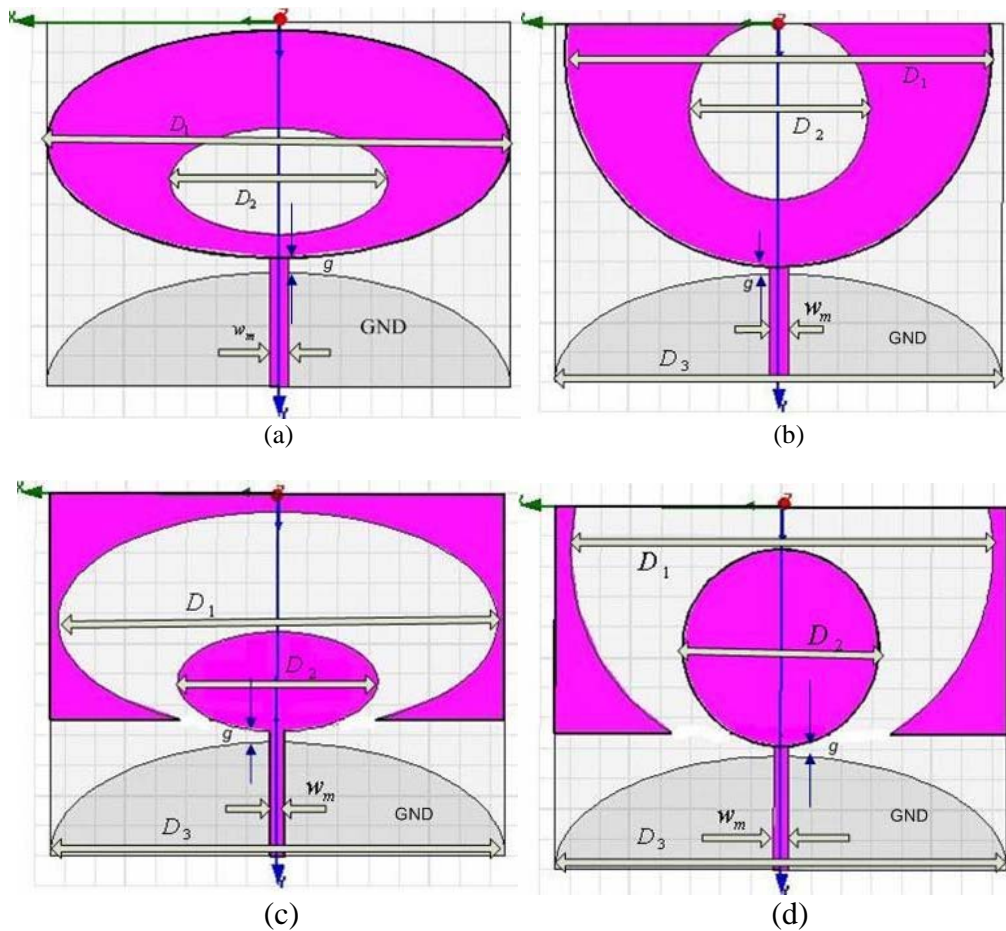


Fig.1. Configurations of the four designed UWB antennas. The radiating element with the feeder is on the top layer while the half ellipse ground plane (GND) is on the bottom layer.

TABLE 1
Calculated and optimized values of design parameters in (mm).

Design Parameter	Values calculated using formulas	Optimized Elliptical Electric Monopole	Optimized Circular Electric Monopole	Optimized Elliptical Magnetic Monopole	Optimized Circular Magnetic Monopole
w	28.6	30	30	30	30
l	22.4	24	24	24	24
D_1	28.6	30	28.6	29	28.5
D_2	14.3	14	13	13.2	13
w_m	1.2	1.2	1.3	1.1	1.1
g	1.2	1.1	0.9	1	1

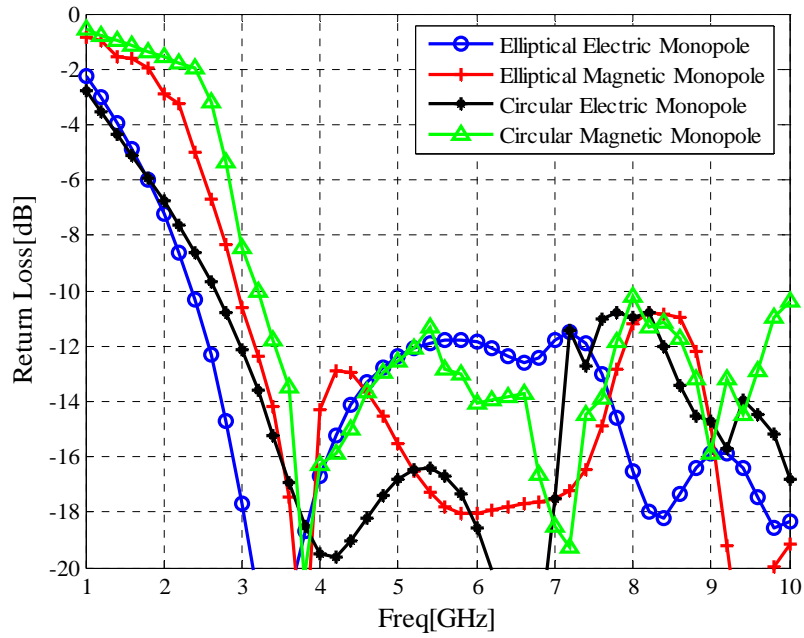


Fig.2. Variation of return loss with frequency for the designed antennas.

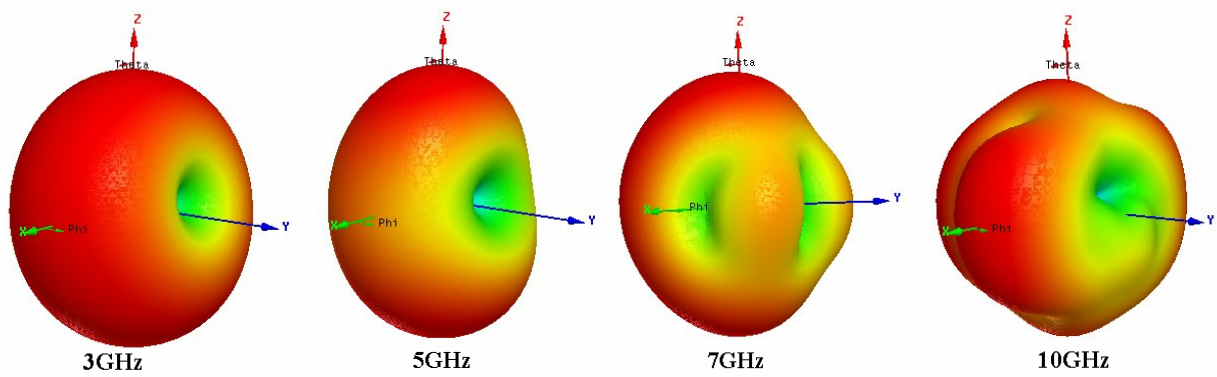


Fig.3. Three dimensional radiation pattern for the elliptical electric monopole at different frequencies.

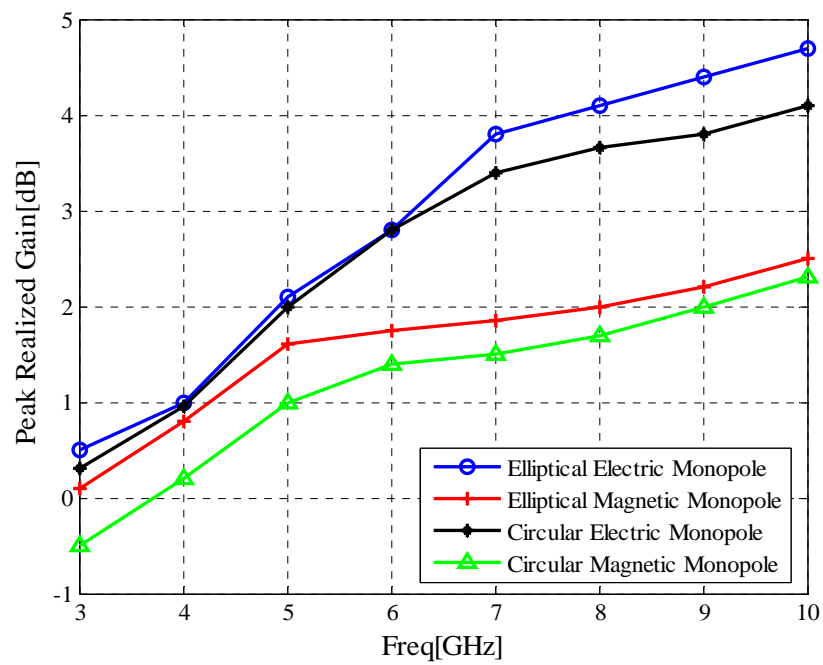


Fig.4. Variation of the peak realized gain with frequency for the designed antennas.